THE RELATIONSHIP BETWEEN EROSION AND HYDROGRAPHIC CHANGES IN THE UPPER MURRAY CATCHMENT, N.S.W.

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(Plates ii–iii; nine Text-figures.)

[Read 29th May, 1935.]

The Upper Murray landscape has distinctive features as the result of the more recent phases of its development. Throughout its extent, all stream courses except those of a torrent character (Text-fig. 5) are marked by the presence of alluvials in two strata—an upper horizon of silt, soil material, or soil, and a lower horizon of pebbles, deposited on the fresh or weathered rock surfaces of the relevant parts of the landscape. Where torrent sections do not intervene, the deposits are continuous from the heads of the streams and valleys to the main alluvial sheet on which the Murray flows: where the courses are broken by torrents, the alluviated conditions apply to the gentler upper and lower valleys (including those of the high plateau, Text-fig. 2), and to breaks in the torrent courses themselves. The usual thicknesses of the strata are 5 to 10 feet for the pebbles, and 5 to 20 feet for the silt, except in the Murray bottoms, where the total thickness is as great as 50 feet. At valley junctions, or where fans from minor hillside streams merge into bottom lands, the pebble horizon is continuous, without discordancies, and the surface presented is of fine material. The only notable exceptions to this rule are found where the main streams (Tooma, Swampy Plain and Indi) emerge from major canyons, and the silt contains an intermixture of pebbles.

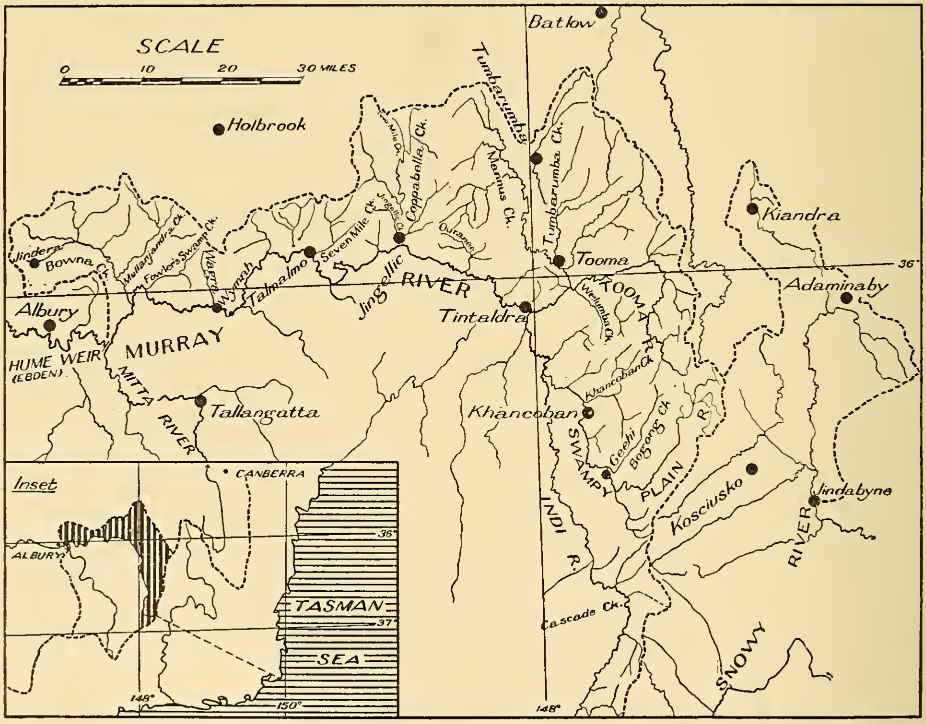
The more recent erosion has been directed towards the removal of these deposits, and makes the fourth stage in the late history of the surface material. The stages are: 1.—The valleys existed without extensive alluvium, and the material taken from their floors and sides was transported by the streams. 2.—The streams carried pebbles, which were deposited on the gentler grades of the main valleys. 3.—Movement of fine rock waste and soil from the middle and upper slope of valley sides, throughout their lengths, increased the colluvial deposits of the lower slopes, and buried the pebbles; at the same time, fine silt carried by the rivers was deposited in the main valleys below the torrent courses. 4.—The most recent action has been directed towards the cutting and removal of these silts, without corresponding deposition in the Murray course above the Hume weir, or on the bottom lands. The cutting has resulted in local terracing.

The definition of the most recent features necessarily depends upon the possibility of measurement within the limits available. Inspection discloses that the forest, scrub, or grass lands of the ridge tops and valley sides are retaining a surface cover of organic soil a few inches thick, whose denudation could only be measured by a great number of experiments extending over a period of years;

information under this heading is not available, so the modern lowering of ridge crests cannot be discussed. On the other hand, the more recent changes in the valley bottoms and alluvials may be defined by departures from pre-existing conditions, and individual examples may be readily measured by surveys with compass, tape, and level. The occurrences show an acceleration of erosion towards the present time, and the term "modern" is applied to cover the period concerned, which is of the order of the 50 or 60 years beginning about 1880 and 1870 respectively. The period itself was determined by reference to individual features which appeared during that time, and to an older series of forms which has been relatively stable since a time antedating the commencement of the modern period: in general, the two are clearly differentiated, and the acceleration of erosion represents a modern departure from the conditions of temporary equilibrium that had been previously attained.

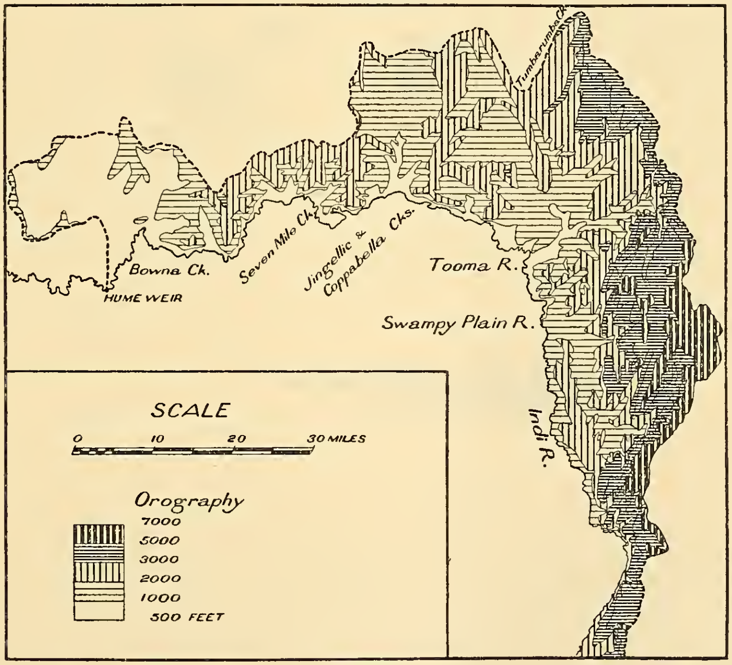
Criteria of Age, and Distribution of Forms.

Modern erosional forms occur on the courses of established streams, or where definite channels are now being cut: individual features have been dated by three principal references—human evidence, trees, and soils, which may be considered in that order.



Text-fig. 1.—Locality map of the New South Wales portion of the Hume catchment. This is barred in the inset, where the Victorian portion is outlined immediately to the south-west.

The largest active cuttings have been formed within living memory: the two major gullies at Tooma began "some fifty years ago", according to residents; that on Seven Mile Creek began about 1890, and three smaller examples at Khancoban are attributed to the period 1879 or 1880 to 1890. One of these latter finally undermined a dam at its then-existing head in the winter of 1926, since when (to 1933) it has progressed at a rate that would give an age of 40 years to the complete feature. In many cases, the re-location of roads and bridges, the destruction of fences by recent cutting, the continued deposition of sand below gullies, and the collapse of banks each winter give additional evidence of the recency of features, and the activity of processes. On the other hand, the presence of large trees or tree relics in channels is proof of greater age, and may serve to define cross-sections which existed before the modern phase of erosion commenced. This is particularly the case with eucalypts of diameter 30″ or more that were ringbarked or felled so long ago that all branches have disappeared, or whose stumps are rotting in the ground (Plate ii, figs. 1, 3, 5). With these, and with living gnarled trees, an age of 40 to 50 years may be assumed with certainty (personal communication from Mr. C. E. Lane-Poole), which is the minimum required to place the surface features outside the modern period. This criterion is generally supported by soil evidence. All channels which are now being eroded have sandy floors, even where the surface being attacked is a mature chernozem soil (as in Plate iii, fig. 2): others, particularly that of Wagra Creek and the middle part of Fowler's Swamp Creek, have maturing black soils on their floors, and graded banks. The soils are forming *in situ*. These latter channels are older

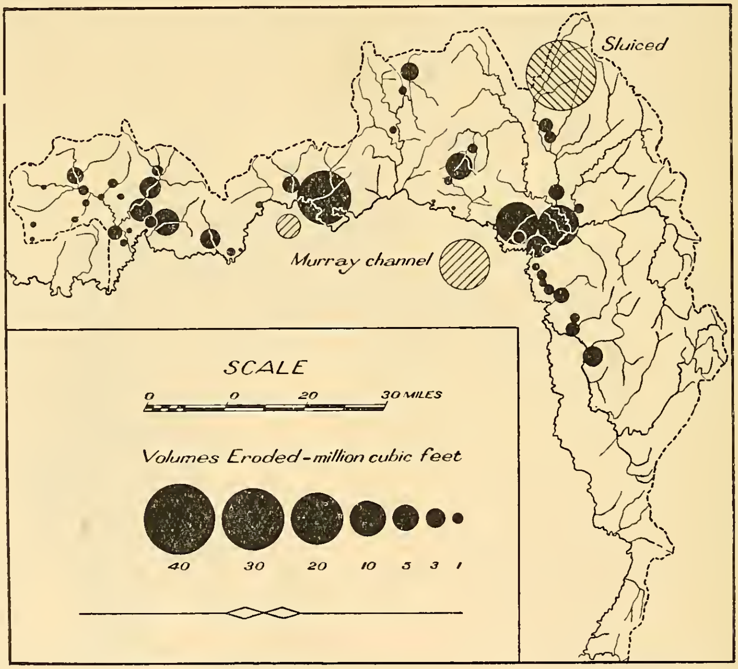


Text-fig. 2.—Orographic map. Approximate definitions are: highlands above 3,000 feet; uplands 1,000 feet to 3,000 feet; lowlands below 1,000 feet.

than the others, and only the portions which clearly diverge from such conditions are reckoned as modern.

Another form of modern erosion is purely artificial, namely, the gold workings on the uplands about Tumbarumba. Much of the excavated material was deposited on the valley bottoms at Tooma, where it is clearly differentiated from the other alluvials in texture, arrangement and vegetation, and gives the only modern example of large-scale deposition. In addition, there has been limited sheet erosion on the cultivated lands of the Bowna Creek and Tumbarumba districts. No estimate has been made of these, because most of the original surface appears to have been preserved, the streams flowing from such lands are generally clear, channels have not silted greatly, and the material carried by the streams in the former district is coarse and fine gravel, which is derived from certain of the channels.

On these criteria, it is apparent that there has been a distinctive phase of erosion confined to modern times, and spread over the half-century beginning about 1880, and the distribution of the volumes displaced in this action may be arranged as in Text-figure 3. This discloses that modern forms are confined to three horizons—the channels of the Murray River and streams immediately adjoining



Text-fig. 3.—Volumes removed by modern erosion, with a probable general order of accuracy of ± 20%. No great deposition is experienced, individual cases being less than 5% of the displaced volume in specific cases. The gold sluicings at Tumbarumba were estimated from deposits at Tooma, and the volume eroded from the Murray channel was approximated by attributing a standard cross-section of removal to all bends in the cutting sections for the general maximum lengths of erosion: the result of the latter is tentative, but it is probably a liberal allowance.

it; alluvial fans and aprons with a general slope of 1° to 3° facing the Murray valley bottoms, and deep soils or fans of similar gradient at the heads of minor valleys on the uplands to an altitude of some 2,000 feet. Apart from the Murray itself, Bowna Creek and the short lowland portions of the Swampy Plain, Indi and Tooma Rivers, this attack is one on the relics of sediments and hill wash that accumulated in the valleys, and on slopes over the whole landscape in times past. The exceptions named have a wide extent and depth on plains of gentle gradient, and have been preserved except in the narrower part of the Murray valley between Talmalmo and Fowler's Swamp Creek, where much of the original material has been removed.

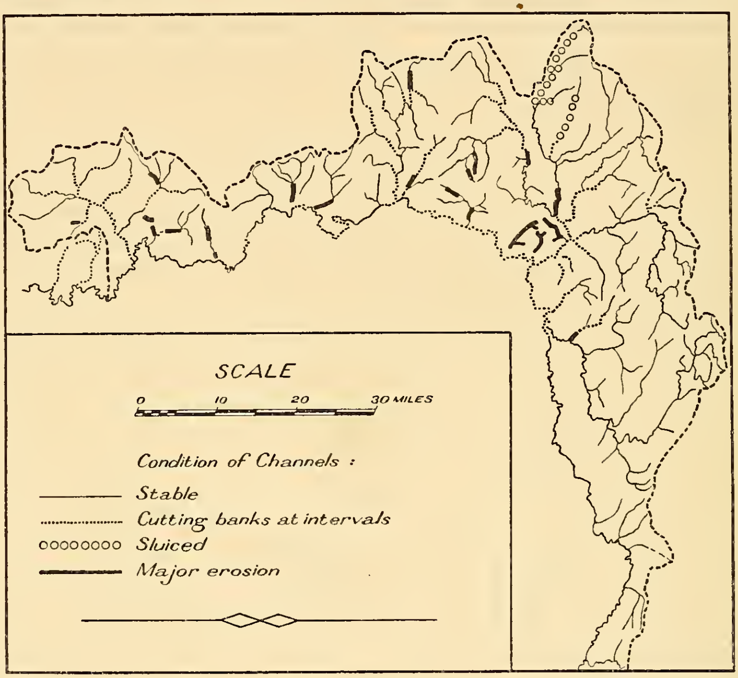
Shape of the Modern Features.

The restricted nature of modern cutting suggests that it is part of a cyclical action, and one may ask whether the forms themselves are in agreement with this. Three distinct considerations enter into the answer, because three sets of forms must be treated separately, namely, those of the Murray, of the Bowna Creek basin, and of the gullied lands.

With the Murray, the essential feature of the channel is, that a normal flood volume in September and October is contained by the banks, except in a few restricted places. In the section between the Swampy Plain River and Tintaldra, there is some activity in the formation of cut-offs (Plate iii, fig. 4), but where the river enters a narrower valley below Tintaldra, billabongs are usually found on one bank only, and are relic features (Plate iii, fig. 1). In times of exceptional flood, river water makes its way through them and over the low-lying plains, but they are usually filled by rain water. Here a change takes place in the river channel: above Tintaldra, there is extensive bank cutting in places by a shallow stream, but in the Jingellic district the river is deeper, and the channel is being extended laterally by the flood stream cutting behind lines of trees, and gradually destroying them (Plate iii, fig. 1). This enlargement may affect each bank at the same time, but it is limited downstream by the contraction of the flood plains below Talmalmo. From here to Fowler's Swamp Creek the course is more stable, and the banks are reinforced at intervals by massive granites: the condition approximates to the tributaries, because most of the sediments have been eroded, and at Wymah the river has sunk its course 30 feet below the old alluvial surface. Summing up, it is found that the modern work of the Murray has been directed towards the stabilization of a single channel below the level of the flood plains and billabongs, and to lateral expansion in places where the channel is not sufficient to carry the present flood volumes.

Turning now to the Bowna Creek drainage, a good deal of variety is met with. The streams are intermittent in character, and flow in channels carved in soil, alluvium and thoroughly decomposed rock at a depth of 8 to 12 feet below the plains. Certain of these channels are stable, particularly in the clay loams of the farming lands towards the west, but others in granite waste are suffering enlargement, or are in process of formation (Plate ii, fig. 1; Text-figure 4). The usual action is lateral enlargement without much change in local stream gradient, or vertical displacement of the stream, but in places this has been varied by a definite entrenchment of the order of 4 to 5 feet (Plate ii, fig. 2). From this, two salient facts emerge: firstly, most of the channels are pre-modern, and they have existed for some time with steep or vertical banks; secondly, there has been a revival in cutting, with the continued formation and recession of vertical banks, and local entrenchment in older terraces. This resembles some phases of the third series of forms.

The gully lands include many new areas of erosion which may be described as simple barrancas or arroyos—in fact, practically all the examples east of Talmalmo merit such terms. On the other hand, Fowler's Swamp Creek illustrates



Text-fig. 4.—Condition of stream channels. The torrent, rock or rock bar channels of Text-fig. 5 may be regarded as having a limited erosion risk attached to them, but others classed as "stable" are merely in equilibrium with present conditions, and carry a much greater risk. Victorian conditions duplicate these.

the whole process of development of such features, from the stage of headward cutting into smooth flats, to that in which an old channel floor becomes silted by wash derived from upstream (Plate ii, figs. 3, 4). Towards the Murray, a road bridge has been almost obscured by drift: here, and immediately upstream, the channel floor appears as a definite terrace, with steep banks separating it from the original surface of the fan, but the features are less perfect in the middle course, where attack has recommenced on vertical banks. Other pre-modern forms along Wagra Creek (Plate ii, fig. 5) bear a close resemblance to the new cut at Talmalmo, but their progress has been limited by a rock channel.

In the foregoing cases, the older features are recognizable as expanded gullies, and they have some counterparts in the Maragle Creek drainage. Evidences of more complete action appear on many other streams in the form of terraces, or terrace relics, for the whole lengths originally alluviated. The greater part of the Maragle, Coppabella, Jingellic and Mannus Creek systems come under this heading (Plate iii, fig. 5), and the modern attack on alluvial remains gives minor cutting with vertical banks at intervals (Text-fig. 4). In general, the tendency is for the slopes to assume the aspect they had before the deposition of alluvials. Modern erosional forms in this catchment of the upper Murray are due to a revival and expansion of cutting forces on the various parts of the landscape, making towards the complete removal of alluvials and deeply weathered material that have survived earlier attacks. A minor cycle of erosion is thus approaching completion, both as regards individual features and the surface as a whole, and the Murray is completing the stabilization of a single channel, which is being adjusted to the needs of the flood stream.

The Factor of Human Interference.

This account of modern features may be regarded as idealistic, because it does not consider the possible effects of human occupation with respect to the clearing of timber and shrubs, and their replacement by grasses. It might be argued that many specific erosional features can be traced directly to some form of human interference, and that streams have become more violent as the result of quicker run-off following partial deforestation, and consequently give increased erosion. This is the essence of Wood's (1928) contention, and it appears to be the standard opinion on the subject at the present time. If it be true, a new minor cycle has commenced as the result of settlement, contrary to the views expressed above. For this reason, the problem of human interference must be treated in its several aspects.

There is no doubt that many individual features are the direct result of human agency. According to residents, the greater part of the major gullies at Tooma were cut after the removal of scrub from shallow channels, and other features, here and at Khancoban, were initiated by drainage channels cut across deep soil or alluvial aprons. In addition, roadside drains at Jindera have been greatly enlarged and deepened. In the same districts, there are also incipient gullies which have been checked by the retention of scrub or trees on their sides. On the other hand, it is not difficult to mention examples of modern cutting despite the presence of trees. The channel of Seven Mile Creek, Talmalmo, is being enlarged at the expense of living trees (Plate ii, fig. 6), and the upper half of its modern length of 2½ miles, representing a quarter of the eroded volume, was swept out of the parkland during the single flood season of 1931. Enlargement of the Murray channel with the gradual destruction of tree lines has been noted, and in the section between the Swampy Plain and Tooma River junctions with the main stream, active cutting is in progress where the river passes through forests, apart from the cutting bends in cleared lands. In fact, the undermined trees set up further erosion by diverting the current against the opposite bank. Similar cases of sylvan destruction are found in the Bowna Creek drainage.

In addition, there are places which could not be protected by trees, namely, the steep or vertical banks left along the older channels, particularly in the lowlands adjoining the Murray. These have survived for some time whilst trees grew on the channel floors, and the soils tended to become mature, and they existed in all the channels classified as showing "cutting banks at intervals" (Text-fig. 4), and especially in those of Bowna, Fowler's Swamp and Jingellic Creeks. Modern revival of cutting and bank recession, which is now taking place rapidly, is a clear indication of changing stream conditions apart from the element of floristic protection, which was slight or non-existent in such cases. Moreover, the actual presence of channels antecedent to the modern period throughout the lowlands and uplands, and their close resemblance to those developing at the present day, is enough to show a continuity of process.

Human interference with natural flora has thus been responsible for the development of some of the new erosional features, mainly of the barranca or arroyo type. Places similar to those attacked were reduced in the past in all districts where the modern attack on relics is active, at a time antecedent to the modern period, and others have lately developed or revived despite protection by trees: cutting has also recommenced on old, unprotected banks. The conclusion is, that settlement has accelerated erosion in some respects, but the places so attacked were those most liable to natural cutting, and which were unstable in any case.

Turning now to the question of accelerated run-off following partial or complete deforestation, it is desirable to have some understanding of the typical Australian forest with respect to run-off. Lane-Poole (1932) has outlined some of the characteristics of the sclerophyllous forests which comprise the greater part of the wooded lands in the Murray basin, as elsewhere. In general, the limiting factor is water rather than light, the forests have an open canopy, humus will not form naturally, and with the older trees, ". . . except in moist situations, all the ground is now quite bare of vegetation or carries but the smallest leafed shrubs and grasses" (p. 283). The floor of the forest is thus characteristically dry, and does not have an appreciable surface layer of humus: indeed, the opening words of the quotation make it clear that the relationship between the forests and moist places is a casual one. In the Upper Murray basin, the forest growth is low (generally less than 80 feet), the slopes vary up to 60°, but are usually in excess of 15° away from the valley bottoms and the uplands about Tumbarumba, and the narrow hanging leaves of the eucalypts combine with these factors to give free admission of wind and sunlight. Exceptions to the rule are comprised in the forests of Mountain Ash (*E. gigantea*) found above 3,000 feet, smaller neighbouring areas of other species, and swamplands of the higher plateaus. Byles (p. 20) estimates the area of Mountain Ash at 87 square miles; the swamplands, with their dense covering of shrubs or tall grasses, cover rather less than 50 square miles, and other forests of close stand are probably not so extensive. The exceptions are grouped in the higher lands, and comprise about 10% of the New South Wales part of the catchment.

How do these forest types influence run-off? The minor areas, particularly the swamps and marshy places, supply water to streams throughout the year, and are thus capable of absorbing rainfall in quantity. This may apply to restricted parts of the close-stand forests as well, but it is not clear that the bulk of the forests make any great difference in run-off as compared, for example, with grasslands. This follows from the general nature of the forest floor, and is supported by experience. For instance, the shafts left by mining prospectors are almost invariably dry; there is an absence of springs and soaks from the mountain sides with vertical ranges up to 5,000 feet, even where the slopes are covered with a thick mantle of rock waste and soil over the impervious rocks; and streams rely for their perennial flow on the limited moist places, mainly in the higher lands. The greater part of the forests has very little extra means of water storage on which the checking of run-off necessarily depends, and it is difficult to see how partial clearing could have a significant influence on the run-off in times of exceptionally heavy rain (e.g., 1917 and 1931).

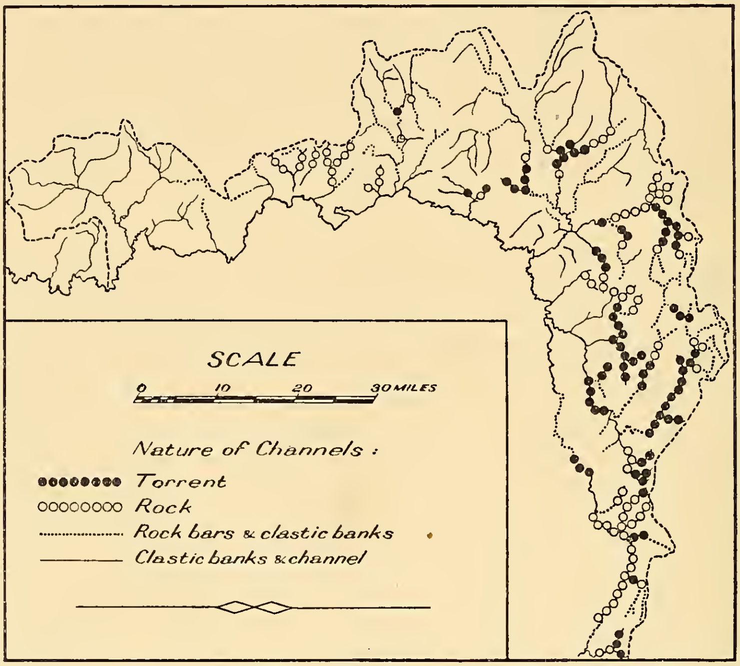
Of the field examples of modern erosion, the cut on Seven Mile Creek, Talmalmo, has the greatest immediate bearing on this topic. The hills forming the catchment are wooded, and have suffered little damage, if any, through fires (Plate ii, fig. 6). Despite this, the rush of the 1931 floods was enough to scour out the upper half of the cut, as already described. It may be concluded that there is no reason for postulating a greatly accelerated run-off from the settled districts as the result of partial deforestation, and the modern features may have had a like origin to those of earlier periods, which were similar in form and position, and lacked the complication of human interference. What was this origin?

Tectonics versus *Hydrography*.

Physiographic and geological work on the coast of New South Wales has revealed evidences of vertical oscillations of a maximum order of 200 feet; the evidences include raised beaches (David and Etheridge, 1890) or shell deposits (Statham, 1892); submerged forest remains (Etheridge, Grimshaw and David, 1896; David and Halligan, 1908), and such features as drowned valleys (Andrews, 1903). From this it has followed that stream features, such as alluvial deposits or terraces, have been associated with these oscillatory movements (e.g., Morton, 1920, in Queensland; Taylor, 1923), and the interpretation of inland features may have been influenced by similar considerations. Thus Andrews (1910) refers to alternate submergences and uplifts as explaining the deposition and terracing of sediments at Forbes and Parkes, in the Lachlan valley, so it may be asserted that tectonic factors have been considered to be the determinants in the sculpture of the more recent land forms of this region.

Such an hypothesis cannot be admitted for the valley of the Upper Murray, for several reasons. Firstly, the modern and pre-modern erosional features in the fans and alluvials are distributed both above and below the torrent sections of all the main streams (Text-figs. 4, 5). These torrent sections, with their rapids and cascades, form a distinct break between the valleys and alluvials of the lowlands, on one hand, and the uplands and highlands on the other. It is difficult to imagine an action extending from the local base-level and passing them without a considerable delay; there is no evidence of such an action at present, but on the contrary similar features are developing, and have developed, at all levels. Secondly, it has been observed that the erosional features of the lowland streams do not involve a general or appreciable change of stream gradient, and they are often spasmodic in distribution along any one course; this applies particularly to Bowna Creek and the Murray itself. Thirdly, it is found that when individual examples are taken, cutting has proceeded without reference to the main stream course. For example, some of the largest cuttings at Tooma are separated from the main streams by widths of unaffected alluvial bottom lands, on which a part of the eroded material is being deposited: on Fowler's Swamp Creek, the Khancoban hillsides, or with the examples in the Tumbarumba uplands, there is a similar tendency to raise the local base-level by this secondary deposition.

From these considerations, it appears that any explanation of the more recent erosional forms on this landscape must apply equally well to all parts, and must also consider the relationships of the alluvials in which they have been cut: in any case, a rejuvenation by some form of differential uplift cannot be allowed. Deprived of this explanation, recourse must be had to the streams themselves, and the cutting explained through variations in their flow.



Text-fig. 5.—Nature of stream channels. The difference between those classed as "torrent" and "rock" is, that the former are scoured by rapid streams, and the latter have stretches of still water, or aggradation flats at intervals.

The Hydrographic Factor.

An examination of the short- and long-term variations in rainfall and stream flow of the Upper Murray and Snowy Rivers has been made separately (Craft, 1934). So far as records show, the small region concerned is a unit with respect to winter rainfall, which is closely related to flood discharges of the rivers: Table I shows this relationship, and supplements the information already published (op. cit., p. 330).

Speaking generally, an earlier period of high flow was centred about the year 1890, and a similar later period commenced in 1917, and extended to the present day: between the two, there was a period in which low floods predominated. These conditions are rather similar to those disclosed by Morrison for the upper Nepean and Murrumbidgee Rivers, and for the Lachlan with greater irregularity (1919, graphs facing p. 13), or by Finucane and Forman (1929, p. 57) for the Swan River, W.A. They are reflected by the incidence of major individual floods, which occurred in the Upper Murray in the years 1878, 1887, 1889, 1890, 1893, 1894, 1906, 1916, 1917, 1918, 1920, 1921, 1923, 1926, and 1931, each being in excess of 4·5 million acre-feet for the year at Albury, whose average annual flow is 3·7 million acre-feet. Thus it appears that certain individual years and

TABLE 1.

Correlation of winter rainfall (May–October) and stream flow records (June–November). Minor imperfections in records (op. cit., p. 328) have been interpolated from neighbouring stations.

Elements.	Period.	Correlation Coefficient.	Probable Error.
Tumbarumba rainfall with			
Batlow rainfall	1891–1932	0·93	0·01
Tooma rainfall	1891–1932	0·98	0·004
Kiandra rainfall	1891–1932	0·82	0·03
Albury rainfall	1891–1932	0·86	0·03
Kosciusko rainfall–Jindabyne flow	1912–1932	0·67	0·08
Kiandra rainfall–Jindabyne flow	1903–1932	0·54	0·10
Batlow rainfall–Jingellic flow	1891–1932	0·86	0·03
Tumbarumba rainfall–Jingellic flow	1891–1932	0·83	0·03
Tooma rainfall–Jingellic flow	1891–1932	0·78	0·04
Albury rainfall–Albury flow	1878–1932	0·86	0·03

seasons have had excessive volumes, which have been associated with major inundations and destruction of human works; from the latter viewpoint, the winter seasons of 1917, 1931, and 1894, in that order, were the most disastrous, and the greatest disturbance of landscape equilibrium is to be expected at such times.

Whether such a disturbance has occurred must, of course, be determined in the field. Any relationship between flow and erosion rests on a purely empirical basis, because there is no rule that would enable one to say that a certain volume, or average, or intensity of flow, represents a critical value at which erosion begins to accelerate. Nor is the abstract trend a more reliable guide, because it is based on averages which have no demonstrable connection with stream work, and its gradient is largely determined by the negative features of excessively low floods: all that one can say is, that the positive annual flow or winter flood trends for the Murray, especially those disclosed by the more accurate records of the present century, indicate a rising flow which gives an expectation of increased stream work and erosion. If the individual major floods, or the periods in which they have been grouped, have been enough to overcome the inertia of those parts of the landscape which they affect, the later smaller flows could reasonably be expected to continue the work on weakened or damaged surfaces, and the recurrence of major floods at intervals would be sufficient to prevent the attainment of a new equilibrium for a considerable time.

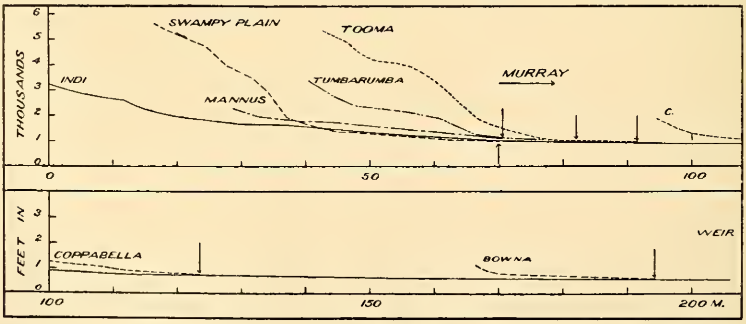
Turning again to the field examples, it will be seen that the earlier period of large flows is approximately synchronous with the commencement of modern erosional features at Khancoban, Tooma and Talmalmo, where the success of the attack was partly due to previous clearing of the ground. If one takes a general view, it is clear that all the modern features—new gullies, receding stream banks, enlarged channels, and the further stabilization of the Murray course at a lower level—many of which are independent of human action, have come into existence after a period of relative stability, in which the pre-modern features were either quiescent or senile. At the same time as this cutting, there has been a great increase in stream activity so that, in the absence of any other competent factor, the erosional revival must be ascribed to the increased cutting power of the streams, following the occurrence of major floods. In other words, the essentials of modern erosion are due to hydrographic changes, involving a slight redistribution of climatic elements, particularly with regard to a greater occurrence of exceptionally low and high monthly rainfall totals.

Following this conclusion, the local surface history since the deposition of the valley alluvials falls into three phases: an earlier period of erosion, possibly of a complex nature, giving the pre-modern channels and terraces; a period of relative stability immediately preceding modern times, followed by the most recent period of erosion, which is now proceeding, and which may not yet have reached its climax.

History of the Alluvials.

If hydrographic change is sufficient to account for modern erosion, it should also be capable of explaining the nature of the material now carried by streams, and the existence and disposition of the alluvials in which the greater part of the modern work has taken place. In other words, it must cover the full alluvial cycle, beginning with deposition and extending to the modern tendency of general removal; also, it must not involve assumptions that cannot be justified in other parts of the eastern Australian highlands, where conditions of alluviation and subsequent erosion are uniformly similar to those existing in the area under discussion. With this limitation in mind, the modern stream channels may be examined, and some definition of conditions made that would substitute deposition for cutting.

Work in Modern Channels.—Where the head streams of the Murray emerge from their gorges, they carry limited quantities of silt and mud, but flow over pebble beds in channels which show little alteration from year to year. The pebbles are similar in size, shape and material to those in the banks which are overlain by drift or silt: where the banks are undermined, masses of loosely cemented or incoherent pebbles are added to the channel. Where the basal pebbles are firmly cemented to form a conglomerate (e.g., Welumba Creek, Tooma, and Two Mile Creek, Jingellic), the channels are scoured clean, with occasional



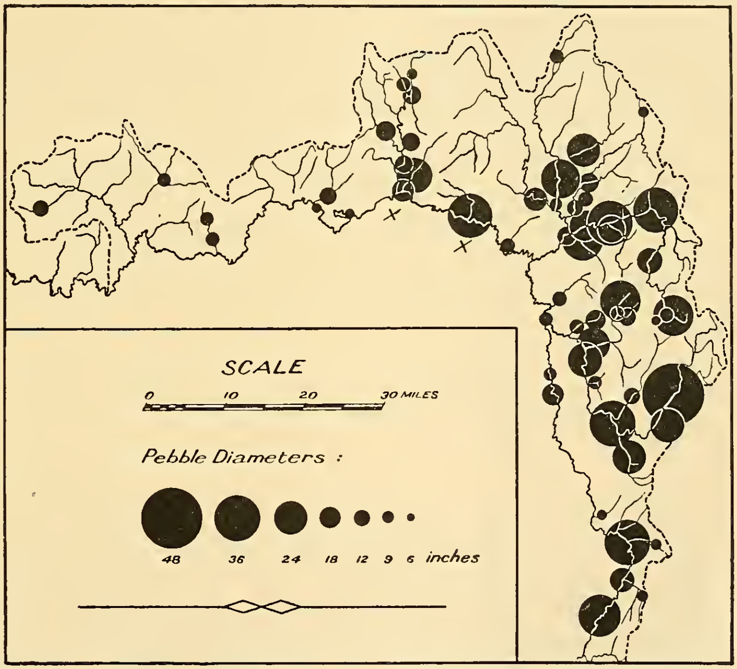
Text-fig. 6.—Talwege of the principal streams. The name "Murray" is applied to the combined Swampy Plain and Indi Rivers.

loose pebbles on the pavement. The ideal ellipsoidal shape is common in all these occurrences; on the other hand, the restricted modern beaches of the Indi, Swampy Plain and lesser streams have flattish or sub-angular pebbles which usually do not exceed 6″ to 8″ in major diameter. From this, it is clear that the modern streams are not supplying large pebbles in quantity to the channels outside the canyons. Two possible reasons for this present themselves: either the streams are not sufficiently powerful to shift and transport the larger material, or they are capable of reducing almost all the rock fragments supplied before emerging from their gorges. The question is one of relative competence.

As a preliminary it will be realized that the torrent courses of the Swampy Plain and Tooma Rivers especially, involving a fall of 2,000 to 3,000 feet within a few miles (Text-fig. 6), favour high stream velocities: added to this, they discharge great volumes in time of exceptional flood, as these figures show:

	Annual.	June–November.
Swampy Plain River at Indi Junction, 1917	92″	69″
Swampy Plain River at Khancoban, 1931	50″	36″
Tooma River at Possum Point, Tooma, 1931	71″	51″

Equivalent depths of water over the whole catchment for the various discharges.

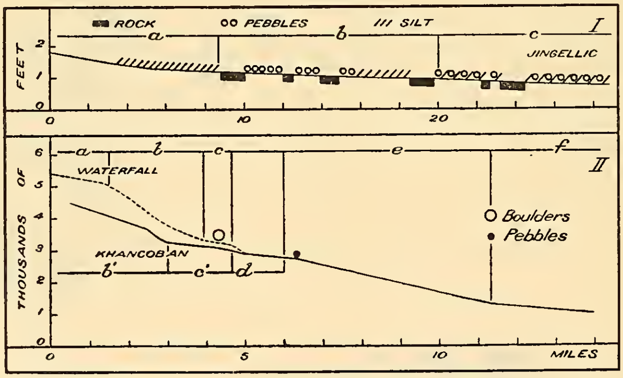


Text-fig. 7.—Major diameters of the largest pebbles found commonly in various places: the letter "X" indicates that the occurrence belongs to the tributary, and not to the Murray. No attempt is made to distinguish newly won material from that derived from the basal pebbles of the alluvials.

The principal highland streams thus have the two essentials of power—gradient and volume—and scour their channels (Plate iii, fig. 6); it would be difficult, if not quite impossible, to imagine conditions in these restricted areas of high country that would give the streams a greatly augmented volume, although high totals might easily become more numerous. If any doubt of the efficiency of the modern transporting medium remains, it will be dispelled by a consideration of the material carried now, or in times past (Text-fig. 7). The streams about Tooma and Jingellic have shifted and rounded material which approaches, in size, any of that carried by the mountain streams, with the exception of boulders of massive rock. Working at a lower elevation with restricted catchments, and forming relatively narrow channels in their torrent sections, their power can scarcely have approached that of the modern Swampy Plain and Tooma Rivers, so the latter may be looked on as highly efficient for purposes of transporting.

This view is confirmed by minor tributaries such as Khancoban Creek, and its highland branch, Waterfall Creek (Text-fig. 8). The latter moves boulders of 30″ to 36″ diameter freely above its cascades, but the pebbles in the bed of Khancoban Creek below the junction contain no visible representatives of the boulders, although they are mainly new material, with a general major diameter of 9″ to 12″. Downstream, the bed of Khancoban Creek on the flats by Swampy Plain River contains large, partly rounded masses of rock to a diameter of 30″, but all are old, and visibly derived from the basal gravels. These streams are typical of the steeper tributaries.

From this it follows that the more powerful rivers and streams must be capable of reducing most of the greater rock fragments in their passage through canyon sections—a conclusion which is in line with the author's previous work on the active Blue Mountain rivers (Craft, 1932*c*, p. 285). Reduction is facilitated



Text-fig. 8.—I. Talweg of Coppabella-Jingellic Creek, to show the occurrence of major bars of hard rock, in black, and the alluvial deposits. *a*—upland valleys and plains; *b*—canyon sections in hard rocks, alternating with open, alluviated valleys; *c*—open valleys and plains adjoining Murray. The pebble horizon underlies the silts. II. Talwege of Khancoban and Waterfall Creeks, to show the relative positions of 30″ diameter boulders, and 12″ diameter pebbles carried by the streams. *a*—highland valleys and swamps; *b* and *b′*—upper canyons; *c*—partly aggraded valley with boulder deposits; *c′*—aggraded, swampy valley; *d*—middle canyon and rapids; *e*—lower canyon; *f*—plains to Swampy Plain River.

by two factors, namely, the presence of great "mills" on the stream courses above the alluviated valleys, and a poor supply of large material. The mills are torrent courses in narrow gorges of hard rock, where streams are excessively turbulent, and have many rapids. Each of the defined torrent courses (Text-fig. 5) may be so described, but those farthest downstream are the most significant, because rocks or pebbles must survive them before deposition is possible in the lower courses. The supply of material must be examined in rather more detail.

The supply of rock waste for transportation appears to be limited by geological character. Coppabella Creek may be used to illustrate the lower valleys and the uplands (Text-fig. 8). With it, the pebbles for alluvial deposits were derived from hard rocks in the middle courses, where the present channels are scoured clean, and massive pavements are exposed. Erosion in these former pebble-making places is very difficult, and the remainder of the landscape is covered with a mantle of soil or weathered rock that is virtually stable against any but direct stream attack, now being directed against the alluvials.

With the higher plateaus, the streams which traverse areas of more fissile rocks (e.g., the sedimentaries or metamorphics of Welumba, Bogong and Khancoban Creeks, and the northerly course of the Indi) gain many rock fragments which are not, and were not, deposited below the gorges. The other streams flow in massive granites or schists, in channels cut in fresh rock, and marked by a general absence of adjoining scree. The general condition of the highlands may be readily summed up by stating that, on the high plateau and its slopes, there is a thick mantle of soil and weathered rock, with relatively few bare cliffs and bluffs, and non-moving screes on slopes up to 40°; on the other hand, the main stream channels and the slopes leading down to them are cleared and rocky, so that landslides into the river are few in number (for one example, see Byles, p. 30). The prevailing aspect is one of stability. It is clear that the streams have the power to shift material supplied to them, but the quantity is small; weaker stuff is reduced to silt, and the stronger to small grades, at the most, before the main alluviated valleys are reached. These conditions are greatly different from those which obtained in the past.

Past Accumulation.—The various deposits under this heading consist of two horizons: the basal material is of pebbles, whose coarseness decreases towards the upper limit, and the surface layer is of fine rock waste, silt or soil. The line of demarcation between the two is sharp, except in a few places adjoining the lower gorges; at Khancoban, for instance, the flats by Khancoban Creek have many pebbles (up to 12″ diameter) scattered through the alluvium, but the limited nature of the exceptions is more remarkable than the fact of their occurrence. What were the conditions for the derivation of this material, and its deposition?

We are fortunate in having a model example of recent origin. Alluvial mining in the Tumbarumba district caused the removal of quantities of fine, sandy drift, which passed the gorges and were deposited on the bottom lands at Tooma: removal is now being commenced by the consolidation and enlargement of a master stream channel. In this case, deposition was caused by the over-loading of the stream without change in the total annual volume of water discharged, and probably without any great variation from normal flood conditions, as large storage dams were not available for the sluicing plants. Can it be denied that the succession of events may not be equally applicable to the past history of the upper Murray?

Turning now to the general problem, it is evident that all the streams carried much greater loads when the alluvials were being deposited than is now the case and that, for a time, they were able to discharge pebbles, even from the lower "mill" courses. These increased loads might be ascribed to greatly accelerated erosion following the disturbance of some limiting factor, such as forest removal, or to increased hydrographic activity. In the light of modern experience, the latter would need to follow a period in which the landscape had been subjected to gentle weathering conditions for a long time, and on which there was much material eligible for removal by streams of increasing competence. The former explanation is attractive for the colder districts, in view of the fact that the highest points in the region were visited by the Pleistocene glaciation, which may have passed as recently as 10,000 years ago (David, 1908). The writer favoured it for the upper Shoalhaven (Craft, 1932*a*, 209; 1932*c*, 289), but the universal distribution of such alluvials in the eastern highlands of Australia, and their varied altitude between sea-level and 6,000 feet makes it appear quite improbable.

The second possible explanation involves factors of process which may operate equally well over the whole landscape, and which are capable of accounting for the sharp distinction between the underlying pebbles and the overlying silts. The one assumption involved—a preliminary weathering during a period of erosional quiescence—is amply justified by reference to many other streams of the region, particularly in granite areas. For instance, the upland tributaries of the Snowy River in the Jindabyne district are cutting through deeply weathered granites, including many cores of exfoliated masses, and those in parts of the Shoalhaven valley about Marulan are winning pebbles and boulders under similar conditions, although deposits from upstream had obscured these in places (see Craft, 1931, Plate iv, 4). In the present area, the lower part of Maragle Creek, Tooma, is the most notable case of similar action, but these individual examples can be paralleled throughout the highlands. The weathering of stream beds and their subsequent erosion to give large pebbles, among other things, are thus found to be general phases of modern or recent action in the region; the assumption that such a process also affected the catchment of the Upper Murray as a whole must, therefore, be regarded as a strong probability, which is practically converted to a certainty when the present defective supply of rock fragments to the streams is borne in mind.

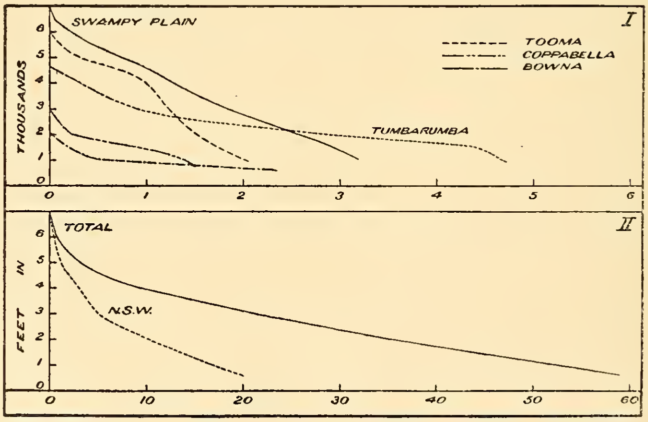
Granting this weathering and later increase in hydrographic power, it becomes necessary to explain the juxtaposition of silt and pebbles in the deposits. Marshall's experiments (1928) demonstrate that, when a mixture of pebbles of various sizes is subjected to movement in water, there is a survival of definite grades, with the elimination of many intermediate sizes. The end product is silt, and there is a general absence of material between the grades of silt and coarse gravel. In other words, if a mixture of rock waste were supplied to the upper parts of a stream and passed along a turbulent course, the actions of grinding, impact and abrasion which Marshall describes would tend to produce graded sizes, and after a time the lower parts of the stream would carry selected pebbles, and silt. If at this stage material were deposited, it should consist of pebbles, because the silt would not be deposited in the agitated water associated with a pebbly river. This appears to have happened with the Upper Murray, where there was a rough sorting of the pebbles according to distance from the lower gorges, and the spaces between the larger pebbles were filled with smaller pebbles, or with sandy drift. The latter may have been derived from country adjacent to the gentler valleys, as the truncated fans on the Indi hillsides above the Swampy Plain junction show; or it may be, in part, a residuum of unreduced material which has escaped from the gorges.

What were the conditions that made for the survival of the pebbles? Evidently the streams were not capable of reducing all the material supplied to them, either because of the greatness of the load, or because the maximum power had not been attained. The former alternative is probable on the assumption of an increase in stream power following a period of general weathering, and the latter is supported by the fact that, even after the discharge of pebbles from the lower gorges had almost ceased, there was a considerable supply of material that was used to form the upper horizon of silt. Probably both factors were effective, and the landscape as a whole suggests that the first rush of large fragments carried from the stream beds and neighbourhoods was succeeded by a flow of smaller material from more distant sources, as the pebbles in stream beds away from the main river valley bottoms are covered with a drift of soil and other fine material. In any case, a critical point is shown at which the pebble supply had decreased so greatly that silts were deposited below the gorges, and in the gentler sections above the lower torrent courses on each of the three main streams (Text-fig. 5). The supply of pebbles did not actually fail, as many are included in the fine silts at Khancoban, Tintaldra, and parts of the Indi River flats, but their occurrence is restricted, and their grading is remarkably uniform; individuals rarely exceed a major diameter of 12″, and few are less than 3″.

These facts appear to indicate that, after the main streams had removed the weathered material from their courses and reached fresh rock, the fragments brought from more remote sources or by weaker streams tended to become smaller, initially, and to be more easily reduced in the passage of the canyons. This action would be assisted by a further increase in stream power, but the latter was not essential. The maintenance of erosive and transporting ability can hardly be doubted, because pebbles were still carried, and the failure of destructive power would have resulted in the survival of the varied material supplied to the rivers in their swift upper courses, instead of its reduction to the fine brown silt of which the top alluvials are formed. In short, the formation and disposition of the alluvials can be explained readily in terms of stream mechanics, with definite limits imposed by the amount of weathering in stream channels, and the quantity of material which became subject to stream attack and removal. In such an action, the observed succession of basal pebbles and upper silts is inevitable and, if the stream volumes are sustained over a sufficiently long period, conditions like those of the present day must be reached. Under these, a defective supply of material is being gained by powerful streams in their upper courses; this is being reduced in the passage of the gorges and the clear streams are removing the existing alluvials from their lower valleys.

The conclusion of simple hydrographic change as the motive force in the inauguration and working out of the alluvial cycle is thus logical and inescapable. It explains the occurrence and juxtaposition of the fine silts and pebbles in the alluvials; the apparent contradiction of hillsides covered with a thick mantle of rock waste and soil, while the torrent channels are scoured clean to expose unweathered pavements; and the development of modern and pre-modern erosional features in the alluvials themselves.

Discussion.—From the viewpoint of altitude or gradient (Text-figs. 2, 6), the Upper Murray landscape as a whole is unstable, with an expectation of a continued reduction towards base-level; however, the process of reduction is slow, and the amount of valley extension since the close of the Tertiary era is limited to canyon formation. The time indicators are flows of basalt which occur at an altitude of 5,000 feet on the eastern divide of Tooma River (Andrews, 1901), with a fall to 3,800 feet in the case of the discontinuous extensions on the eastern divide of Tumbarumba Creek, or 2,000 feet in the case of Mannus Creek. There is a further extension into the valley at Tooma (Plate iii, fig. 3), where the base of the flow is at 1,100 to 1,200 feet, and comes to the level of the modern valley floor. The extrusions are of a general Pliocene age (Browne, 1933, 34), and immediately to the east of the Tooma drainage, Tumut River has cut a canyon to a depth of more than 2,000 feet below the basalt (Andrews, 1901). In the Tooma district, canyon recession is of the order of 5 miles on Tumbarumba Creek, with a probable maximum depth increment of 600 feet, so that post-Tertiary action from the local base-level has been responsible for the removal of basalt from valleys, and for limited canyon extension. The general form of the valleys below Tooma as regards depth and talweg is thus found to be the result of pre-basaltic action and, with no sign of later faulting, the existing relief of the whole surface dates back to the Pliocene, at least, together with the essential form of the Tooma and Swampy Plain Rivers (contrast David, 1932*a*, p. 95, who favours Andrews, 1910, p. 421, in granting regional late-Tertiary uplift, stream rejuvenation, and canyon cutting). It follows that, whilst absolute stability is not possible under the existing conditions of slope and altitude, the mean departure from equilibrium in post-Tertiary time has been comparatively small. Thus the hypsometric curves (Text-fig. 9) and the talwege (Text-fig. 6) are not so unstable as their form might lead one to believe.



Text-fig. 9.—Hypsometric curves for the principal stream basins; the horizontal scales are in hundreds of square miles. In II, the total is for the Murray above the Hume weir, of which the Victorian portion is taken from the International Map of the World, 1:1,000,000 (Sheets SI 55 and SJ 55), whilst the New South Wales portion, separately and in the total, is from surveys by B. U. Byles and the author, based on trigonometrical data.

This has been largely brought about by geological structure (refer to David, 1932*b*). The area consists essentially of a granite mass, with local coverings and inclusions of sedimentary and metamorphic rocks; the upper intrusive surface underlies towards the west. Thus a summit plane which appears to be not far below the original upper limit of the granite is found on the highest plateau at 7,000 feet, at the head of Snowy River, but it falls away in all directions, so that the country rock of the Albury district, at altitudes below 1,000 feet, consists of sedimentaries. The granites are diversified by masses of extra resistance (e.g., the hill of Plate iii, fig. 1), of which the greatest forms the high plateau to the west of the Upper Indi–Murray River line. Effects of this may be seen in the cases of small tributaries to the Indi, such as Cascade Creek, which flow on the high granite plateau, and then fall steeply to the metamorphics of the river line; of Khancoban Creek and its tributaries, whose downcutting is held up by granite bars immediately below the graded middle valleys (*c* and *c′* of Text-fig. 8, II); and by the presence of a falling belt of metamorphics on the western slopes of the highest mass, between Welumba Creek, Tooma, and the head of Indi River. The shape and resistance of the upper granite surface, therefore, gives an expectation of rectilinear hypsometric curves for the Murray and its highland source basins; the actual curves found are of this form, and are thus normal to the terrain concerned, and are not indicative of recent tectonic disturbance and major instability of land forms. Similar factors have existed in the development of certain minor streams: Tumbarumba (including Mannus) and Coppabella Creeks have their lower torrent courses in an irregular east-west trending belt of hard schists and quartzites, which stand up in square profiles higher than the basins and local plains upstream, and impose minor inflections on the hypsometric curves by reason of the steep slopes associated with them, and the limited extent of the lowest country in each stream basin. With the disappearance of this factor to the west, other tributary drainages (e.g., Bowna Creek) take on a normal form.

On this landscape, the various disturbances of local equilibrium are closely related to one another, and are parts of a cyclical action in four stages, namely: 1.—Simple valleys existed without alluvial deposits. 2.—A period of cutting followed, with the formation of rounded and ellipsoidal pebbles in all channels, and their deposition in gentle valleys. 3.—This stage saw fine drift carried from the upper and middle slopes of the valley sides, while the streams carried and deposited silt, destroying most of their limited pebble supply in the process. 4.—The present condition is one of general equilibrium on the valley sides, and cutting in the alluvials, with a limited number of sub-angular and flat pebbles carried by the main streams as new material. In this scheme, modern erosion represents an acceleration of the fourth stage, with major floods as the disturbing factor. The tendency is to produce a topography like that which existed before the deposition of the two horizons of the alluvials, and the critical point was attained at the beginning of the fourth stage, when there was a break between the dominance of deposition, and the later assumption of cutting. Such conditions only apply to portions of the Murray River; the fact is recognized by Fenner (1934, fig. 4*b*), who distinguishes between the river of the uplands above Albury, that of the billabong lands below Albury, towards the Murrumbidgee junction, and the simple channel of the lower course in slightly raised country, where cutting again predominates (Fenner, 1930). As we have seen, the conditions responsible for the existence of the old billabongs above Albury—the wandering of a river on the plains, with deposition balancing removal—no longer apply, but there is cutting, even on straight courses, with no apparent deposits of a permanent character. It may be remarked, that the stranding of these billabongs had been previously noticed by Smail (Interstate Royal Commission, 1902*b*, 279).

The processes of the fourth stage are resulting in the formation of a definite terrace series, and it would be competent for a repetition of the cycle to give a new series of deposits and terraces, because the talweg slope involved (average 0° 7′ between Khancoban and Albury) has been sufficient for the removal of sediments that existed before the present alluvials were deposited. The action is evidently the result of the application of disturbing conditions over the whole landscape, and it gives the simplest possible explanation of the arrangement of river deposits, and their terracing. Many other examples to which attention has been paid (cf. Barrell, 1920; Steers, 1932, ch. v) occur close to sea-level, and near coasts, and are thus particularly susceptible to explanation by reference to changes in the level of the sea relative to the land. Such an explanation would be very far-fetched in the cases of the inland rivers of Australia, such as the Upper Murray, with terrace forms in a vertical range of 10, 20 and 50 feet in each locality, and at a distance of more than 1,000 miles from the river mouth. More extreme cases may be cited, such as the Upper Murrumbidgee and its terraces at an elevation of 3,700 feet (Craft, 1933*a*, Plate ix, 3), but the whole tenor of evidence in the eastern highlands is, that recent alluvials have been subjected to terracing at all altitudes and distances from the sea, and the alluvials operated upon in each case had the characteristic horizons of silt and pebbles. The alluvial cycle described for the Murray may well be of general application, even where later cutting and terracing are due to stream revival through external causes in the vicinity of coasts.

This leads to the consideration of the longer range history of the Upper Murray. It has been shown that material for the pebbles and silts of the alluvials of the whole landscape was derived by a general action on the stream channels and valley sides, at all elevations; this was in accordance with the existing hypsometric curves, and would give a slight general lowering of them without any great departure from their shape. Is it possible that the whole development of the landscape has followed similar lines since the beginning of the formation of the plateau?

The summit plane of the existing surface has a maximum fall of 5,000 feet from the highest points on the eastern Murray divide to the plateau edge near Albury, in a distance of 80 miles; the western limit of the country originally subjected to this particular uplift has naturally been obscured by erosion. The existing fall of the summit plane is equivalent to a slope of 0° 40′, and the uplift involved in the formation of the highlands has simply resulted in the formation of this slope, and the revival of streams on it. This contrasts with conditions on the eastern or Murrumbidgee-Snowy fall from the Murray divide, where the old summit plane at 5,000 to 7,000 feet on that divide has been largely obliterated towards the east, in the formation of successive peneplain levels (Craft, 1933*a*). With a definite tilt of limited value, stream revival is not concentrated at a point, as in the case of the scarp edge of a block mountain system, but it is distributed along the whole lengths of the streams affected with a natural maximum towards the downstream side. This gives the phenomenon of uniform revival and cutting, an ideal case being that of the Nepean tributaries on the "Nepean Ramp", immediately south of Sydney (Taylor, 1923, 67). If a point of favourable inflection existed, a superimposed impulse of headward erosion would operate, and would gradually die out as it progressed upstream.

If a more complex example be supposed, with uplift in stages and peripheral extension of the uplifted country, there would be a series of stream revivals, with each succeeding one further removed from the centre of the affected area. With the gentle regional slopes existing in eastern Australia, of a general order of 1°, and a consequent limitation of the effect of each revival, especially during the attack on hard basement rocks, the talweg of a major stream would be expected to take on a rectilinear form. The conditions have been satisfied in this region (Craft, 1932*b*, 259), and a rectilinear-talweg stream class exists, including the Lachlan, Macquarie, Murrumbidgee, Snowy, Condamine and Castlereagh Rivers (Craft, 1933*b*, 452). As a contrast, other rivers have talwege and valleys determined by block mountain conditions, with a predominating impulse of headward erosion directed upstream from a limited zone, causing the regular migration of a fall line; typical examples are the Clarence and Macleay.

From this it follows that the gentle tilting of a surface without major inflections will give a uniform stream revival throughout the length of the streams affected, but a major inflection in the surface will give rise to an impulse of headward erosion. When the tilting effect is predominant, especially if a series of uplifts be envisaged, the stream talweg assumes a rectilinear form that is only gradually made concave by the operation of the normal forces of weathering and erosion. In such a process the gorges invading the central mass or core represent a very late stage of landscape development—a stage which is now being attained by the Upper Murray, operating on the slopes where outward expansion of the highlands has been a minimum.

Conclusions.

1. Modern erosion in the Upper Murray catchment is an acceleration of the attack on alluvial deposits in the main valleys, and along minor streams.

2. Acceleration of cutting has been due to increasing flood intensity, and to the occurrence of groups of exceptional floods. These have been caused by slight variations in the number of months of extremely high rainfall in the normal flood season, without any great climatic change.

3. A normal cycle of deposition and removal is shown with increasing stream power. Four principal stages are recognized, namely: 1.—A condition of equilibrium, involving weathering of stream beds and the landscape in general, with streams of insufficient power to remove all the weathered material. 2.—An increase in stream power, involving an attack on stream beds and surroundings to give rounded and ellipsoidal pebbles which are deposited in the gentler valleys. 3.—The removal of finer material from the valley sides, its partial deposition along minor streams, and the reduction of the balance in the torrent courses, together with a decreasing supply of rock fragments, to give fine silt, and a few pebbles. These are deposited on the pebble beds in the valleys. 4.—With the removal of the most unstable material, and the exposure of unweathered rock in torrent courses, the streams become clear; a maintenance of their power results in the attack, terracing, and removal of the alluvial deposits, with periods of maximum and minimum activity governed by flood conditions.

4. The size and shape of material carried by streams from the highlands depend on the stage of the cycle that has been reached.

5. With the maintenance of stream power, the larger grades of material transported become impermanent, and there is a strong tendency for the whole load to be reduced to the form of silt. Hence the cutting power in rock channels may decline with increasing flood volumes, because a poor supply of abrasional weapons is gained from the fresh channel rock, and individual pieces are more quickly destroyed.

6. The more recent erosion has tended to preserve the form of rectilinear hypsometric curves for the Upper Murray, and for certain of its principal tributary stream basins.

7. The original development of the topography depended on acceleration of cutting as the result of gentle tilting during the uplift of the highlands. Revival took place simultaneously along the whole lengths of the stream courses.

8. The streams of New South Wales have been subjected to two forms of rejuvenation. In the first, gentle regional tilting has been concerned, but in the second the presence of major surface inflections, or block mountain conditions, has caused the development of a dominating impulse of headward recession, which migrates upstream from a narrow zone.

9. On the estimates for modern erosion on the Upper Murray, the annual displacement measured is of the order of 50 acre-feet. If this be applied to the whole catchment above the Hume weir, the gross annual displacement is of the order of 150 acre-feet. On this basis, a period of the order of 8,000 years would be required to give a volume equal to that of the Hume reservoir (1,250,000 acre-feet). Unknown factors are the sheet waste from the catchment, and the proportion of eroded material passing the weir, but the potential useful life of the structure appears to be of the order of some thousands of years, on the experience of landscape change in the past half century.

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(For general acknowledgements, see Craft, 1934.)

EXPLANATION OF PLATES II-III.

Plate ii.

1.—Stream in Bowna Creek Basin (at Gerogery), to show tree relics in channel, and the nature of modern cutting.

2.—View on Mullanjandra Creek, to show terracing, with a new channel in the foreground, and unprotected banks in the background. Erosion has re-commenced on the latter.

3.—Middle section of Fowler's Swamp Creek, to show modern bank cutting in alluvial relics and soil, with the fence to the right enclosing a flat of matured soil.

4.—Lower part of Fowler's Swamp Creek, with terracing in the alluvial fan and plain: this dies out with the fall towards the river.

5.—Pre-modern channel of Wagra Creek, Wymah, to show form, maturing soils on the channel floor, and trees which have been cut down *in situ*.

6.—Seven Mile Creek, Talmalmo. Note the wooded catchment, the destruction of trees, and the modern attack on the valley alluvials. A terrace above the flats represents an old valley floor, and the cross-section of the pre-modern course is in the foreground.

Plate iii.

1.—Valley of the Murray below Jingellic, during the normal flood of October, 1933. The stream is enlarging its channel by attacking each bank, and the old billabongs are seen to the right.

2.—Modern attack on mature chernozem soil overlying pebble layers, upper part of Coppabella Creek, about 1,300 feet altitude. This also shows the general form of the uplands, looking downstream.

3.—Valley of Tumbarumba Creek, Tooma, with the valley of Maragle Creek between the ridges on the left, in the cleared portion. The background shows the lower part of the Tooma River gorge, and the altitude range is from 900 to 5,200 feet. The valley floor towards the foreground consists of sediments from gold workings at Tumbarumba, and the nearest hill on the left is part of a Tertiary basalt flow.

4.—Valley of the Murray above Tintaldra, with the Swampy Plain valley beyond the ridges in the middle distance, and Mt. Kosciusko in the far distance towards the right. Note the enlargement of the stream channel, the attack on tree lands, and the billabongs on the wet plains. The surfaces of alluvial fans and aprons are accordant with this plain, with a few minor exceptions on very steep hillsides.

5.—Maragle Creek, Tooma. The stream is attacking relics of hill wash and alluvium, which overlie pebbles and bouldery granites. This is a type of the channel described as having "cutting banks at intervals", and the equilibrium valley form is well shown. (Photo, B. U. Byles.)

6.—Torrent course of the Swampy Plain River above Geehi, showing the channel scoured in fresh rock, with few boulders and pebbles. This is a typical "mill" section. (Photo, B. U. Byles.)